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Integrating Diverse Calibration Products to Improve Seismic Location

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INTEGRATING DIVERSE CALIBRATION PRODUCTS TO IMPROVE SEISMIC LOCATION

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ABSTRACT

The monitoring of nuclear explosions on a global basis requires accurate event locations. As an example, under the Comprehensive Test Ban Treaty, the size of an on-site inspection search area is 1,000 square kilometers or approximately 17 km accuracy assuming a circular area. This level of accuracy is a significant challenge for small events that are recorded using a sparse regional network. In such cases, the travel-time of seismic energy is strongly affected by crustal and upper mantle heterogeneity and large biases can result. This can lead to large systematic errors in location and, more importantly, to invalid error bounds associated with location estimates. Corrections can be developed and integrated to correct for these biases. These path corrections take the form of both three-dimensional model corrections along with three-dimensional empirically based travel time corrections. LLNL is currently working to integrate a diverse set of three-dimensional velocity model and empirical based travel-time products into one consistent and validated calibration set.

To perform this task, we have developed a hybrid approach that uses three-dimensional model corrections for a region and then uses reference events when available to improve the path correction. This Bayesian kriging approach uses the best *a priori* three-dimensional velocity model that is produced for a local region and uses this as a baseline correction. When multiple models are produced for a local region, uncertainties in the models are compared against each other using ground truth data and an optimal model is chosen. We are in the process of combining three-dimensional models on a region-by-region basis and integrating the uncertainties to form a global correction set. The Bayesian kriging prediction combines this *a priori* model and its statistics with the empirical calibrations to give an optimal *a posteriori* calibration estimate. In regions where there is limited or no coverage by reference events the corrections will be based primarily on the model. The integrated *a priori* model is particularly important in these areas. In regions with adequate calibration events, we are demonstrating improvement in event location through the reduction of regional bias. In regions with sparse or no ground truth, the *a priori* model will need to be spot-validated with the use of dedicated calibration experiments or through the use of mining explosions, where available.

Key Words: Calibration, product integration, event location, reference events, model corrections, validation

Objective

The monitoring of nuclear explosions on a global basis requires accurate event locations. The travel-time of seismic energy is strongly affected by crustal and upper mantle possibly leading to large systematic (bias) errors in location and, more importantly, to thus to invalid error bounds associated with location estimates. At Livermore, we are working to implement our unified framework that combines empirical- and model-based corrections that can account for these biases. These path corrections take the form of both three-dimensional *a priori* and tomographic model corrections along with three-dimensional empirically based travel time corrections. This paper focuses on the LLNL effort this year to integrate a diverse set of three-dimensional velocity model and empirical based travel-time products into one consistent and validated calibration set.

Research Accomplished

This year we have worked with Sandia and Los Alamos to implement a framework that allows us to design, build, integrate, and visualize calibrations that originate from both internal DOE and external sources. This is not a new project. Instead, it is the natural extension of our empirical and modeling calibration efforts over the past five years.. A large part of our effort at Livermore has been concerned with generating standardized detection, travel-time, and amplitude correction volumes within user defined geographic sub-regions. The tessellated output of this tool combines these sub-regions into one global correction set. This global set is then fed directly into the appropriate detection, location, and discrimination algorithms and leads to the primary improvement in the detection, location, and discrimination. In this process, we address four core issues.

KB Product Visualization. We are working to provide improved end-to-end visualization of all calibration events (i.e. ground truth events), their uncertainties, constructed models, empirically kriged surfaces on a region-by-region basis. We can now provide a completely integrated demonstration of the DOE laboratories' geographic regionalization.

Direct Calibration Interaction. We are working to visualize, access, and potentially alter within any geographic subregion the calibration events, statistics, model, and/or kriged surfaces, if required. Sub-regions can be rapidly redefined. This may be especially useful when constructing adding calibration information in regions where calibrations and uncertainties need to be added in an efficient fashion.

External Product Integration. Allows the laboratories to identify polygonal sub-regions that correspond to regions covered by external contractors. Contract research provided to LLNL within that geographic sub-region can be seamlessly incorporated in the DOE KB. Product integrators will assess uncertainties in contributed calibrations and will compare these uncertainties with other contractor / DOE contributions in the region. The optimal model will be selected and assigned to that sub-region.

DOE Coordinated Analysis. Standardizes DOE calibration efforts into one single format and access tool. Ensures the seamless coordination and integration of projects performed at the two laboratories in the Middle East – North Africa (MENA), East Asia, FSU. Sub-regions can be easily merged at boundaries and models can be altered to properly merge analyses made by different laboratories in regions that overlap.

This framework is being developed in multiple phases. The first phase involves standardizing the suite of statistical, kriging, modeling and tessellation tools that have been developed by LLNL and SNL over the past two years.

Framework for Integrating Calibrations

The overall goal of our framework is to provide a flexible, interactive environment in which an analyst can produce, test, and manage calibration information for seismic stations. This framework supports a calibration effort that improves monitoring performance by improving precision of model predictions and by providing proper characterizations of uncertainty.

Producing calibration information for a region involves the creation of calibration surfaces and/or tessellations for all the stations within the region. This requires the production and refinement of dozens of kriging subregions, statistical subregions, and variograms. Producing these entities is inherently an interactive process in which the researcher must observe the effect of changes, and use that feedback to decide whether continued modification is required.

The framework we have designed handles multiple mesh (tessellation) and station-phase-attribute surfaces at once. For one of these surfaces, a suite of declustering algorithms are incorporated to spatially de-cluster raw data. Distinct data groups should be spatially associated within product subregions. Product subregions can be created and edited in terms of their boundaries. Various trends and velocity models can be removed within each subregion. Outlier removal is supported but not encouraged. Statistical tests, graphical methods, and analyst discretion (which may be arbitrary) are supported as methods to identify outliers.

Data with similar spatial statistics are grouped withing statistical regions. Statistical regions are completely independent of kriging regions, so statistical regions may overlap any number of kriging regions. However, it may be common for statistical and kriging regions to have identical boundaries. Statistical analysis is performed on data within statistical regions. Statistical analysis consists of stationary or non-stationary, isotropic or anisotropic variogram modeling. In subsequent releases, more general variogram modeling will be incorpoated. Incorporating non-parametric non-stationary, anisotropy, and/or co-variograms (mixing data sets) are some of the options that work towards increased variogram generality. Variograms are then assigned to a specific kriging region. After assigning all variograms, the data set can be kriged.

It may be desirable to krig on an optimally spaced (irregular) grid (e.g. tessellation). The tessellation may be optimized for one kriged surface or a collection of surfaces. If tessellation is desired, the bounds of the tessellation and the lowest density spacing should be specified. A collection of surfaces over which the tessellation is optimized must also be specified. The resulting tessellation (node and triangle information) should be saved so subsequent surfaces can be kriged on the same mesh.

Using this process we are able to assure that realistic modeling uncertainties are assigned and propagated on a regional basis. Calibration data and models from a diverse set of groups can be integrated into one correction surface suite and the uncertainties are effectively normalized globally, We continue to validate this process with newly acquired ground truth events and refine it as required.

Conclusions and Recommendations

In general, we have developed a hybrid approach to location that uses three-dimensional model corrections for a region and then uses reference events when available to improve the path correction. Our approach is to select the best *a priori* three-dimensional velocity model that is produced for a local region and then use this as a baseline correction. When multiple models are produced for a local region, uncertainties in the models will be compared against each other using ground truth data and an optimal model will be chosen. We are working towards implementing a calibration integration process of combining three-dimensional models on a region-by-region basis and integrating the uncertainties to form a global correction set. The Bayesian kriging prediction combines the optimal model combination and its statistics with the empirical calibrations to give an optimal *a posteriori* calibration estimate.

To aid this process we have developed a general framework to provide a flexible, interactive environment in which an researcher can produce, test, and manage calibration information for seismic stations. This approach allows a general statistical analysis on a regional basis and results in a self consistent global calibration set.

References

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What Are Technical Monitoring Goals?

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Seismic Location

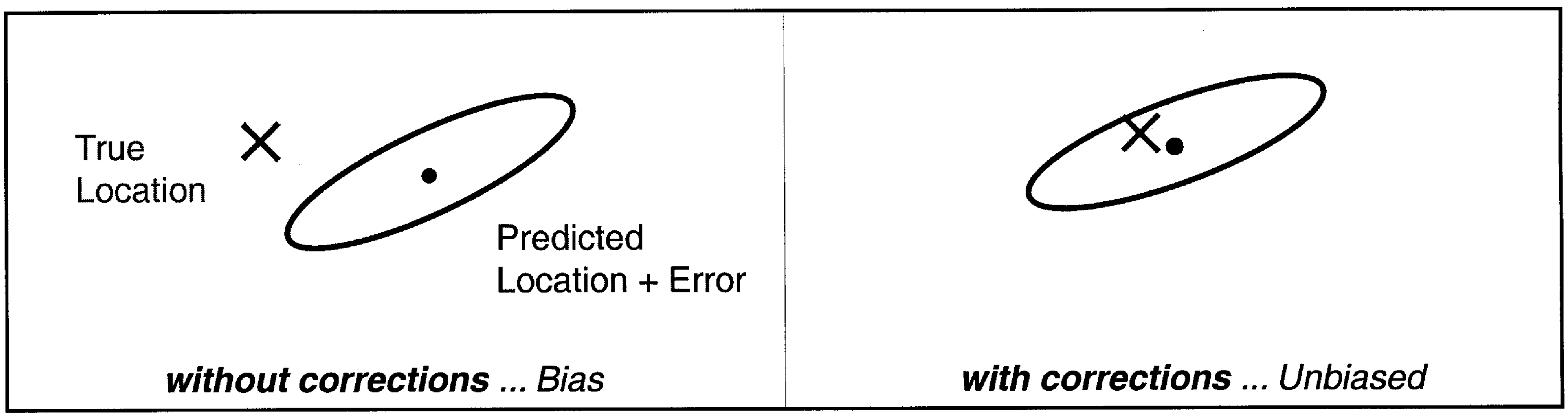

Fig. 1

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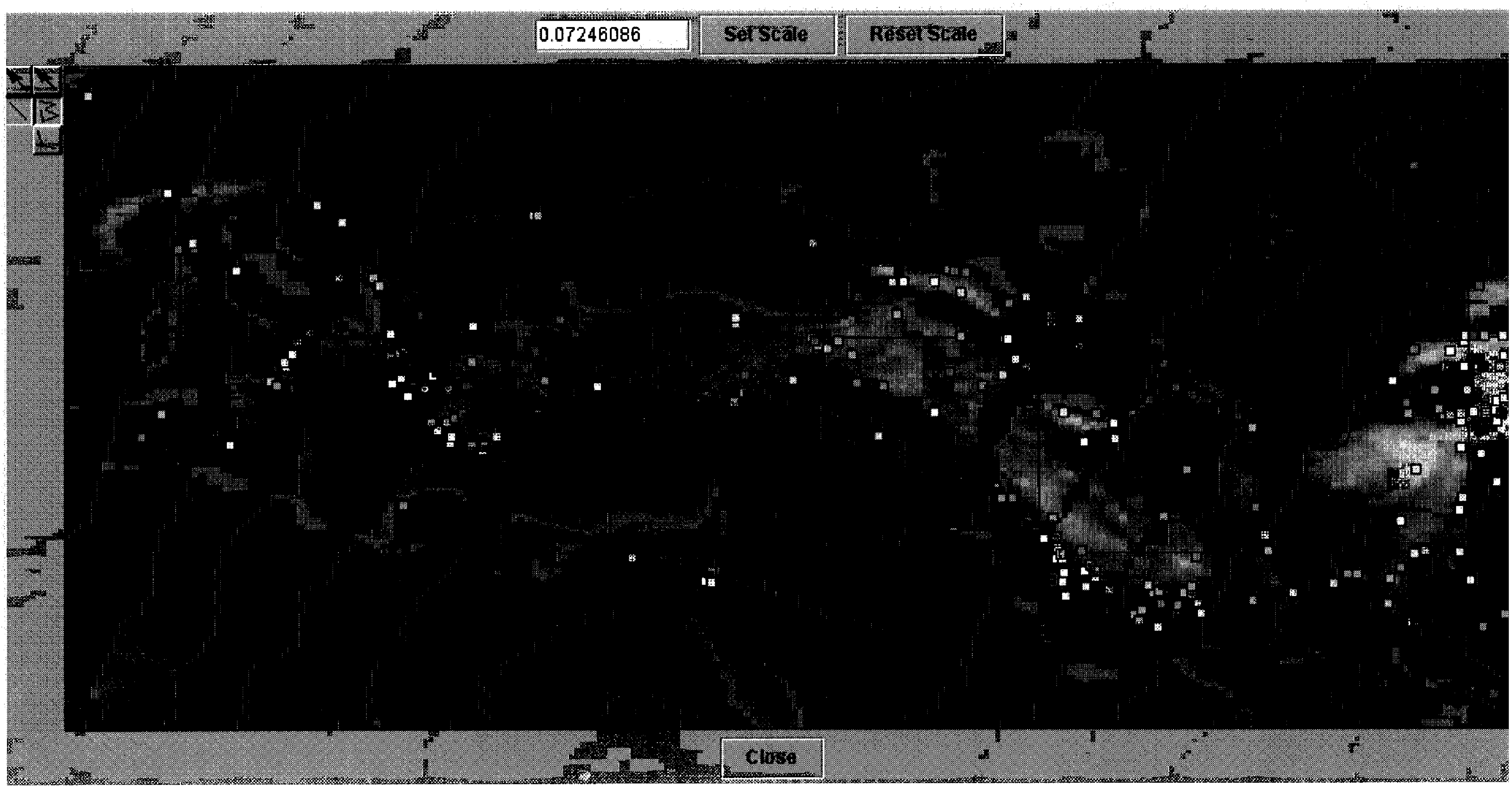

Fig 2

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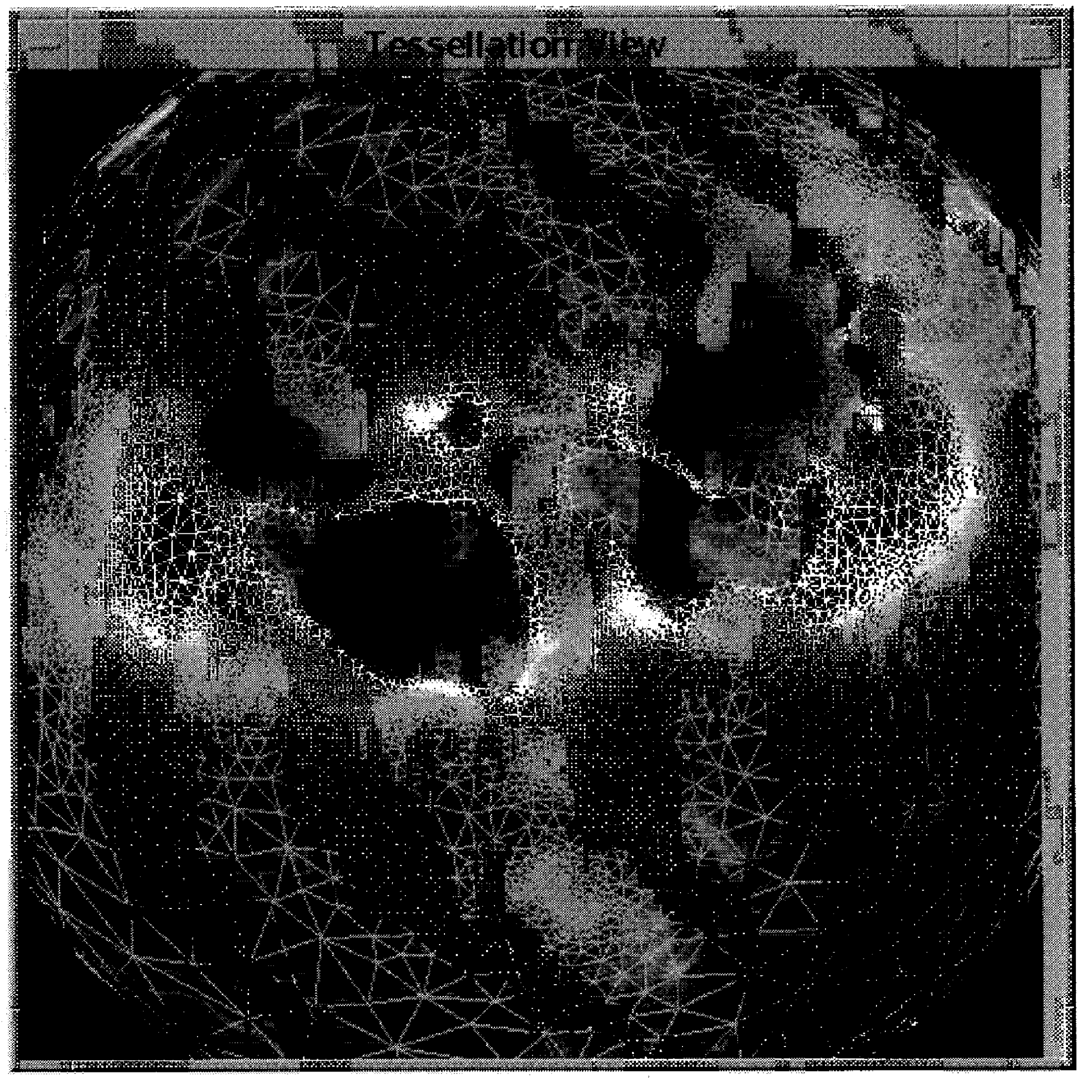

Fig 39

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Fig 8b

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